# DYNAMICS OF PROPORTIONAL SPEED CONTROL VERSUS SERVO SPEED CONTROL OF A HOSE / CABLE SPOOLING DEVICE FOR DRUM

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# *DINAMICA REGLĂRII PROPORȚIONALE A VITEZEI VERSUS SERVOREGLAREA VITEZEI DEPĂNĂTORULUI DE FURTUN / CABLU AL TAMBURULUI*

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## ABSTRACT

*This article presents and analyses in two cases the dynamic performance of regulation and control of the linear speed of an electro-hydraulically driven mechatronic axis. In the first case, the flow control is performed with a proportional hydraulic directional control valve, while in the second case the control is performed with a servo-valve. The linear mechatronic axis is part of a complex subsystem used in both agriculture and industry that allows the precise winding of a hose / cable on a drum with the help of a spooling device, which conditions the positioning of the hose. The speed control of the hydraulic cylinder with bilateral rod on whose liner the spooling device is fixed is performed in a closed loop with the help of transducers and a programmable controller (PLC).*

## REZUMAT

*Articolul de față prezintă și analizează în două situații performanțele dinamice de reglaj și control al vitezei liniare a unei axe mecatronice acționate electro-hidraulic. În prima situație reglarea debitului este realizată cu un distribuitor hidraulic proporțional, iar în cea de a doua situație reglarea se realizează cu o servovalvă. Axa mecatronică liniară face parte dintr-un subsistem complex folosit atât în agricultură cât și în industrie ce permite înfășurarea precisă a unui furtun /cablu pe un tambur cu ajutorul unui depănător care condiționează poziționarea furtunului. Controlul vitezei cilindrului hidraulic cu tijă bilaterală pe a cărui cămașă este fixat depănătorul este realizat în buclă închisă cu ajutorul traductorilor și a unui controler programabil (PLC).*

## INTRODUCTION

In plant life, depending on the vegetation phases and development stages, there are periods during which the water scarcity affects the level and quality of production. These periods are known as "critical phases for humidity". Meteorological factors (air humidity, heat, light, precipitation) in turn have a direct influence on the need for irrigation. Precipitation is the most important source of moisture for the soil and an important parameter for assessing the need for irrigation; it is characterized by the multiannual average, with high variability for different climatic zones. By irrigating crops is meant bringing and distributing water on cultivated soils, for the following purposes: (*Biolan et al, 2010; www.scrigroup.com, 2020*)

- to increase the soil moisture to the limit required by each cultivated plant, so that the growth takes place normally;
- to protect crops from heat and drought;
- to remove or dilute harmful salts from saline soils;
- to ensure the performance of agricultural works in optimal conditions. (*www.seretransilvania.ro, 2020*)

The methods of arranging the agricultural crops for irrigation and the technical elements of irrigation (watering norm, minimum requirements, intensity of application and degree of water spraying) depend fundamentally on the type and properties of the soils. In the correct management of the completion of the water necessary for the plants by irrigations, knowing the water consumption of the plants in the given soil and climate conditions plays an essential role. Sprinkler watering, which is one of the most efficient methods of distributing water to plants, is applied by means of irrigation equipment with positional watering or watering while the equipment moves. The sprinkler system with watering while the equipment moves, with drum and hose, model type IATF, RAINSTAR and GH + MTP, has been developed in several constructive variants regarding the driving group: group with hydraulic bellows motor with single / double effect, driving group with turbine or thermal engine, Figure 1.

The drive group ensures the recovery and controlled rolling (one coil next to another) of the hose on the drum for feeding the sprinkler trolley. Irrigated surfaces are strips with a length of 300-600 m and a width of 36, 40, 44 and 54 m, for working pressure values of 3.0; 3.5; 4; 4.5 bar.

**Fig. 1 - Drum and hose irrigation system**
*(www.bauer-at.com, 2020; www.ferbo.net, 2020; Roiss et al, 2020*)

Use of the irrigation system: the system is transported to the irrigation site; it is connected to utilities and by means of the tractor, the hose is unrolled. At its end there is the trolley that ensures irrigation with sprinklers; simultaneously with the irrigation process recovery of the hose, whose linear speed is constant to ensure the prescribed watering norm, also begins. The dependence between the watering norm and the hose recovery speed is presented in Figure 2.

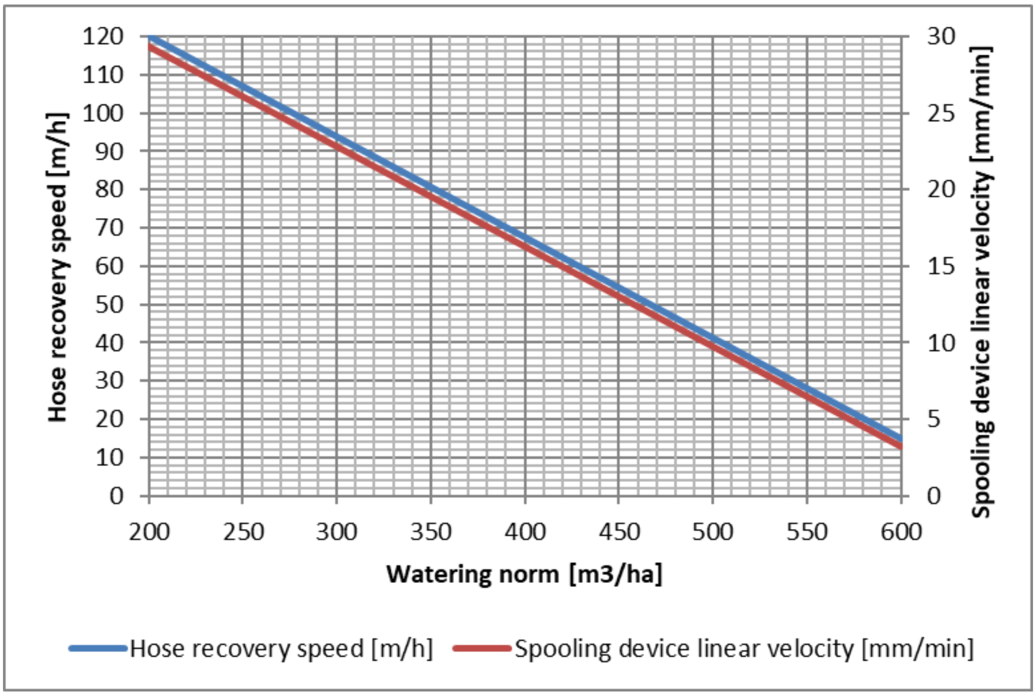


**Fig.2 - Variation of hose recovery speed and linear velocity of hose spooling device depending on watering norm**

At the end of the winding cycle of the few layers of the hose, the equipment is rotated 180 degrees or is moved to irrigate a new plot of land, and the cycle repeats until irrigation of the crop is completed.

The graph in Figure 2 presents the variation of the parameters hose recovery speed (m/h) and spooling device speed (mm/min), for values of the watering norm in the range 200-600 $m^3$/ha. The minimum watering norm (200 $m^3$/ha) is ensured for a recovery speed of the hose of 120 m/h, and a recovery speed of the spooling device of 29.25 mm/min, whereas the maximum watering norm (600 $m^3$/ha) - for a recovery speed of the hose of 13 m/h, and a recovery speed of the spooling device of 3.25 mm/min. For watering norms between the minimum and maximum values, assessments can be made regarding the technical and functional parameters of the driving group, the recovery speed of the hose and also the linear velocity of the spooling device. For example, for the watering norm of 400 $m^3$/ha the hose recovery speed will be 64.5 m/h and the spooling device speed - 15 mm/min.

The spooling device is shown in Figure 3 with a black outline; it consists of a hydraulic cylinder and four rollers that have the role of guiding the hose. The hydraulic cylinder has bilateral rods that are fixed and through which the two chambers of the cylinder are fed with hydraulic oil. (*Pott et al, 2013*)

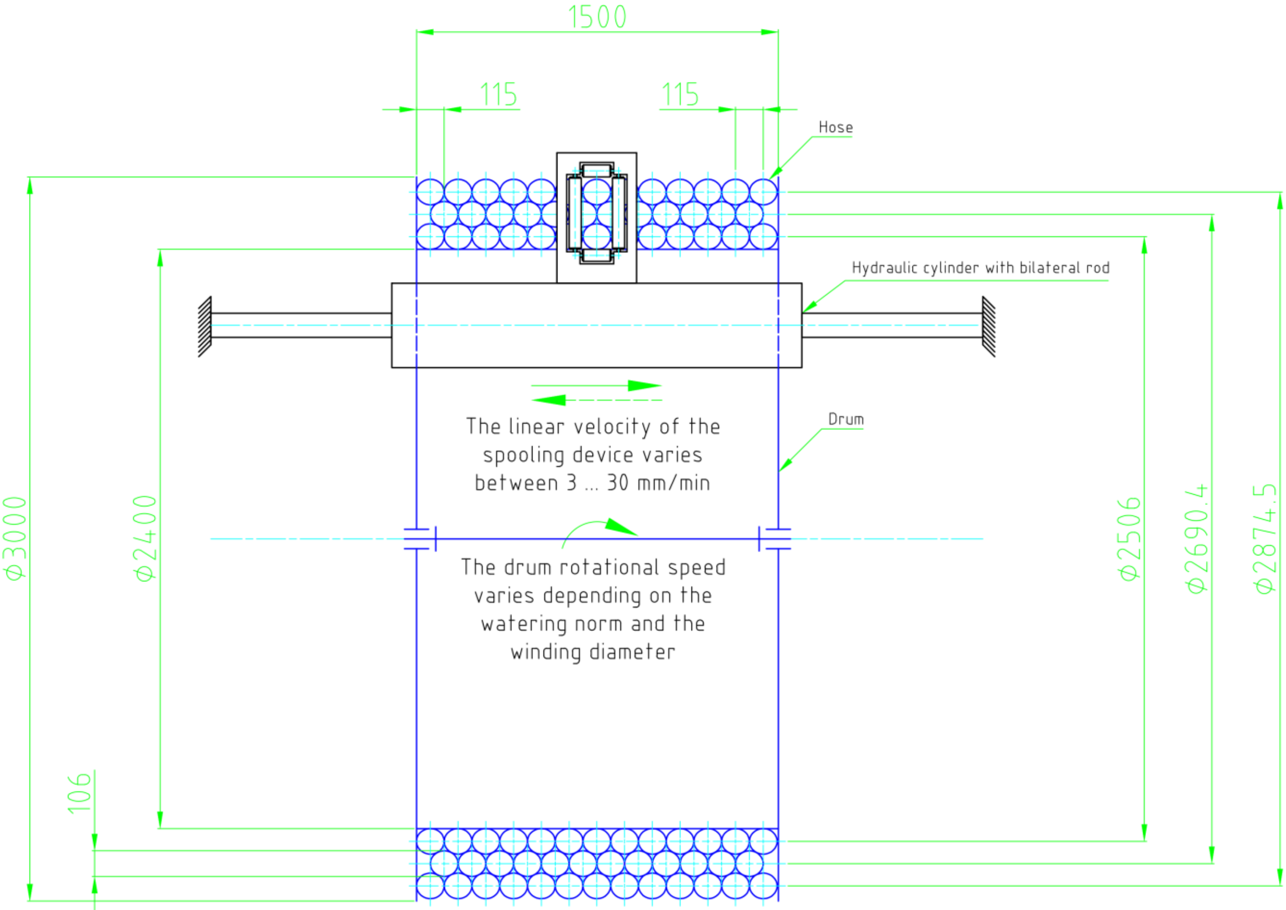


**Fig. 3 - Schematic diagram of the process**

Table 1 presents the results of several calculations from which the numerical simulation was started.

**Table 1**

**The results of the calculations for the chosen irrigation system variant**

| | Layer 1 | Layer 2 | Layer 3 | Total |
|---|---|---|---|---|
| **Drum winding diameters** | 2506 mm | 2690.4 mm | 2874.5 mm | - |
| **Hose circumference by diameter** | 7.873 m | 8.452 m | 9.031 m | - |
| **Number of turns per layer** | 13 | 13 | 13 | 39 |
| **Hose length per layer** | 102.347 m | 109.878 m | 117.397 m | 329.62 m |
| **Hose recovery speed** | 107 m/hr (for 250 $m^3$/ha watering norm) | | | - |
| **Hose recovery time on the layer** | 3443.4 s | 3696.8 s | 3949.8 s | 11090 s |
| **Linear travel velocity (process value)** | 26.137 mm/min | 24.345 mm/min | 22.786 mm/min | - |

## MATERIALS AND METHODS

The numerical simulation showing the dynamic speed control performances in the two distinct control cases has been performed by using Simcenter AMESim 2020.1. The automatic electrohydraulic system for adjusting the linear velocity of the spooling device and also the simulation parameters are shown in the Figure 4 below. (*Xu et al, 2020; Zhang et al, 2020*)

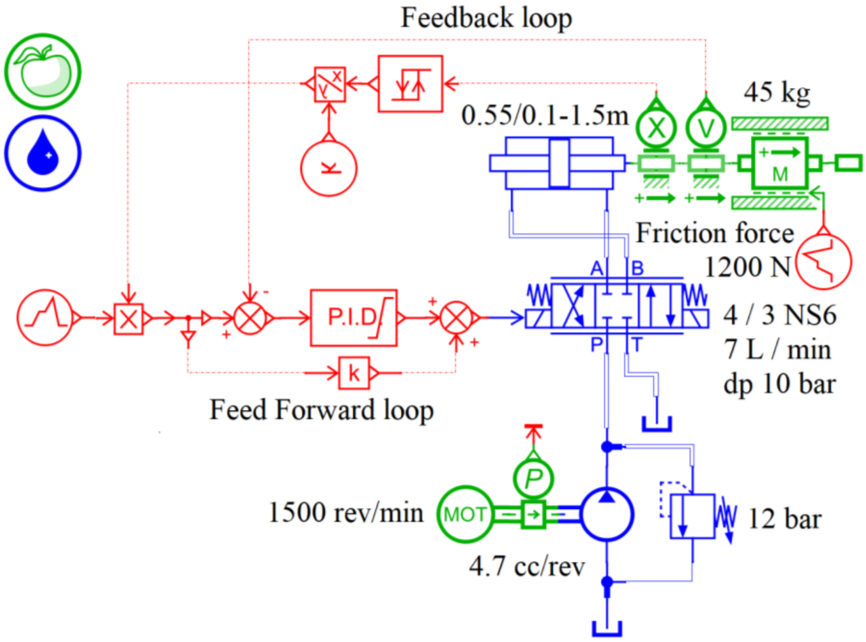
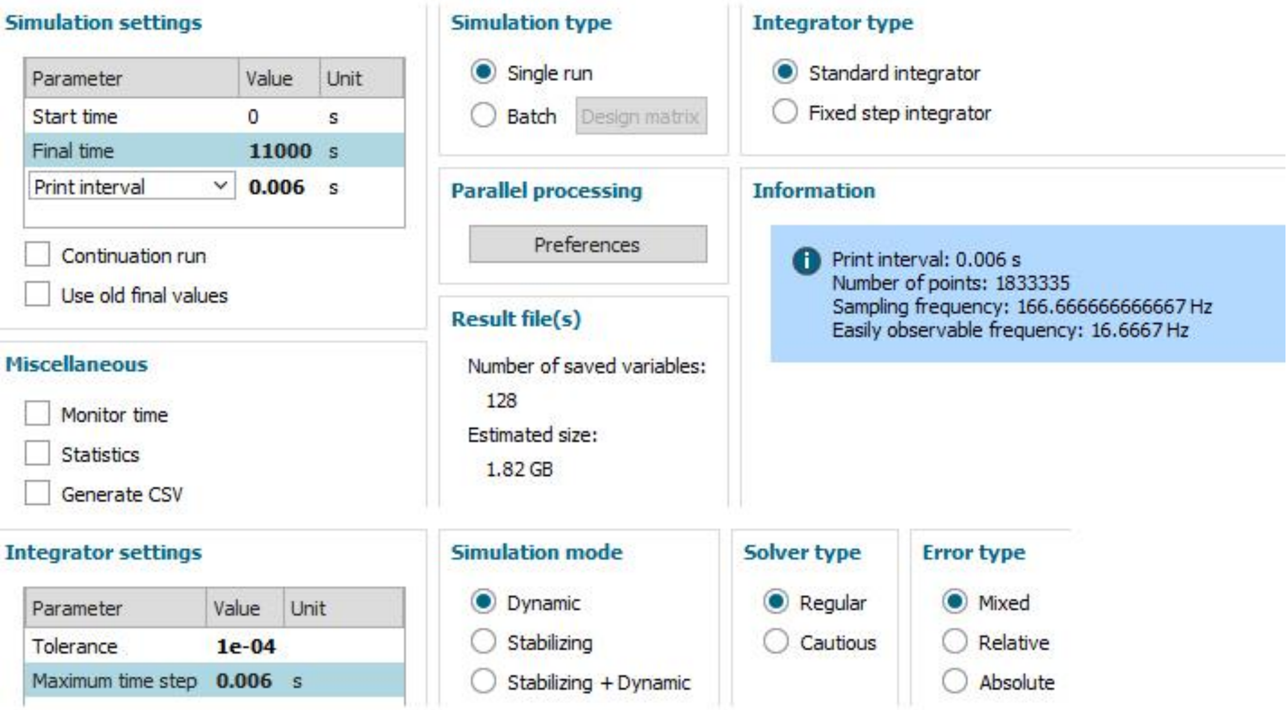


**Fig. 4 - Schematic diagram of the process**

The proposed solution involves driving the spooling device with a hydraulic cylinder whose velocity is regulated by a PID controller with feedback and feed-forward, which improves the adjustment precision and controls an electrohydraulic device for regulating the flow of the proportional control valve.

The simulation settings are shown in Figure 5, in which one can notice that the simulation time is about 3 hours, the sampling frequency is 166 Hz, and print interval is 0.006 s. (*Ali et al, 2020; Wang, 2020*)



**Simulation settings**

| Parameter | Value | Unit |
|---|---|---|
| Start time | 0 | s |
| Final time | 11000 | s |
| Print interval | 0.006 | s |

☐ Continuation run
☐ Use old final values

**Simulation type**

● Single run
○ Batch

**Integrator type**

● Standard integrator
○ Fixed step integrator

**Parallel processing**

**Information**

Print interval: 0.006 s
Number of points: 1833335
Sampling frequency: 166.666666666667 Hz
Easily observable frequency: 16.6667 Hz

**Result file(s)**

Number of saved variables:
128
Estimated size:
1.82 GB

**Miscellaneous**

☐ Monitor time
☐ Statistics
☐ Generate CSV

**Integrator settings**

| Parameter | Value | Unit |
|---|---|---|
| Tolerance | 1e-04 | |
| Maximum time step | 0.006 | s |

**Simulation mode**

● Dynamic
○ Stabilizing
○ Stabilizing + Dynamic

**Solver type**

● Regular
○ Cautious

**Error type**

● Mixed
○ Relative
○ Absolute

**Fig. 5 – Simulation settings**

The Ziegler – Nichols tuning method with some overshot was used to calibrate the PID controller. The response to the step signal before calibrating the two systems is shown in Figure 6. (*Afram et al, 2020*)

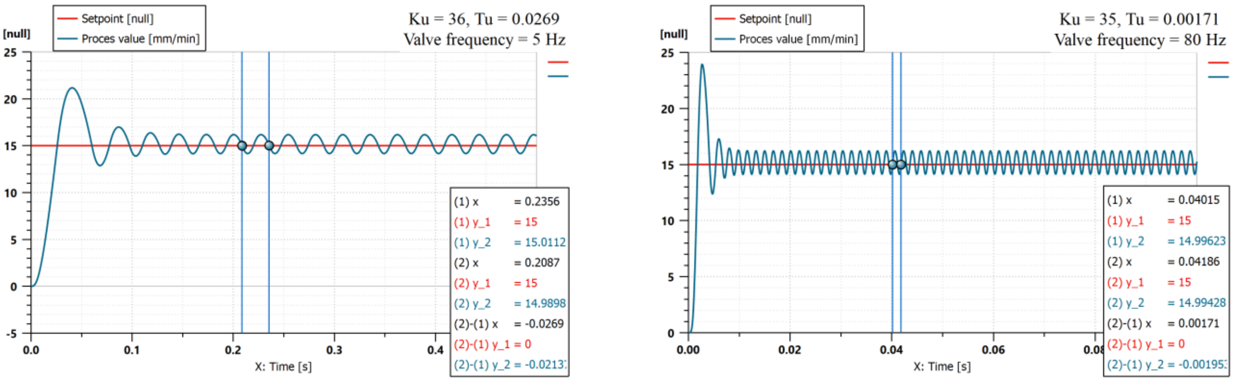


**Fig.6 - The response of the two systems (proportional control valve - on the left side and servo valve – on the right side) to the step signal before calibration**

Figure 7 shows the adjustment performance of the two compared systems and the parameters chosen for the PID controllers; one can notice that the system with proportional control valve (left side) is 4 times slower and has a stabilization time of about 0.2 seconds. (*Fliess and Join, 2009; Samygina et al, 2018*)

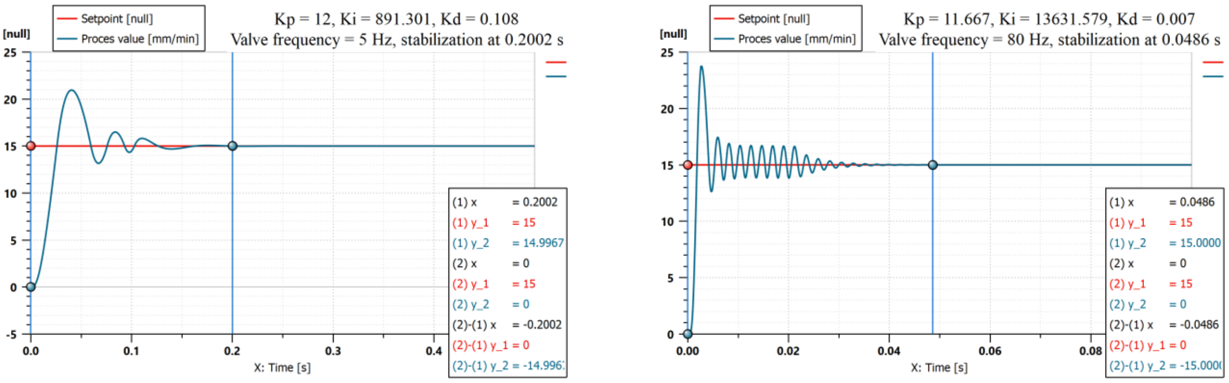


**Fig.7 - The response of the two systems (proportional control valve - on the left side and servo valve – on the right side) to the step signal after calibration**

## RESULTS

The group of graphs in Figure 8 below shows the variations over time of the mechanical and hydraulic parameters of the system.

The graph in the upper left corner shows the input parameters of the hydraulic pump, for example the pump is driven by a thermal engine with a constant speed of 1500 rev/min, evolution is shown in red on the graph, the torque required for the pump is shown in blue and its numerical value is 0.9 N/m. If the speed and torque are constant, the power consumed by the system can also be only constant - presented in orange and with a value of 140 W.

The graph in the upper right corner shows in red the constant flow rate of hydraulic oil circulated by the pump in the system; it has a value of about 7 l/min; the orange curve shows the system pressure which has a constant value of 12 bar because the excess flow of the system (shown on the graph with the blue curve) is discharged through the pressure valve at the pressure at which it is adjusted in order to achieve resistive flow regulation.

The graph in the lower left corner shows in red the evolution over time of the spooling device position. One can notice that it makes 3 strokes corresponding to the 3 diameters of the hose winding on the drum; the blue curve shows the variation of the linear speed of the spooling device over time, and its acceleration is presented in orange.

The graph in the lower right corner shows in red the evolution in time of the position of the directional control valve spool, and in blue the velocity of the spool valve.

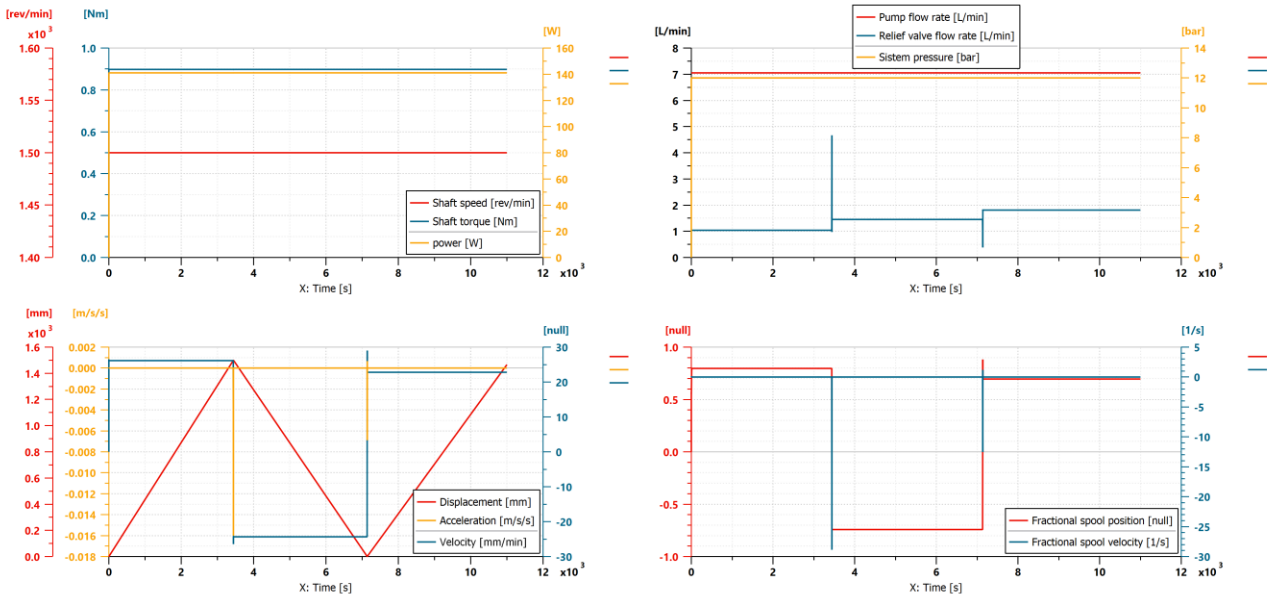


Fig. 8 - Variations over time of the mechanical and hydraulic parameters of the system

The group of graphs presented in Figure 9 shows the evolution in time of the internal (the bottom of the chart) and external (the top of the chart) parameters of the PID controller. (*Gao and Ye, 2020*)

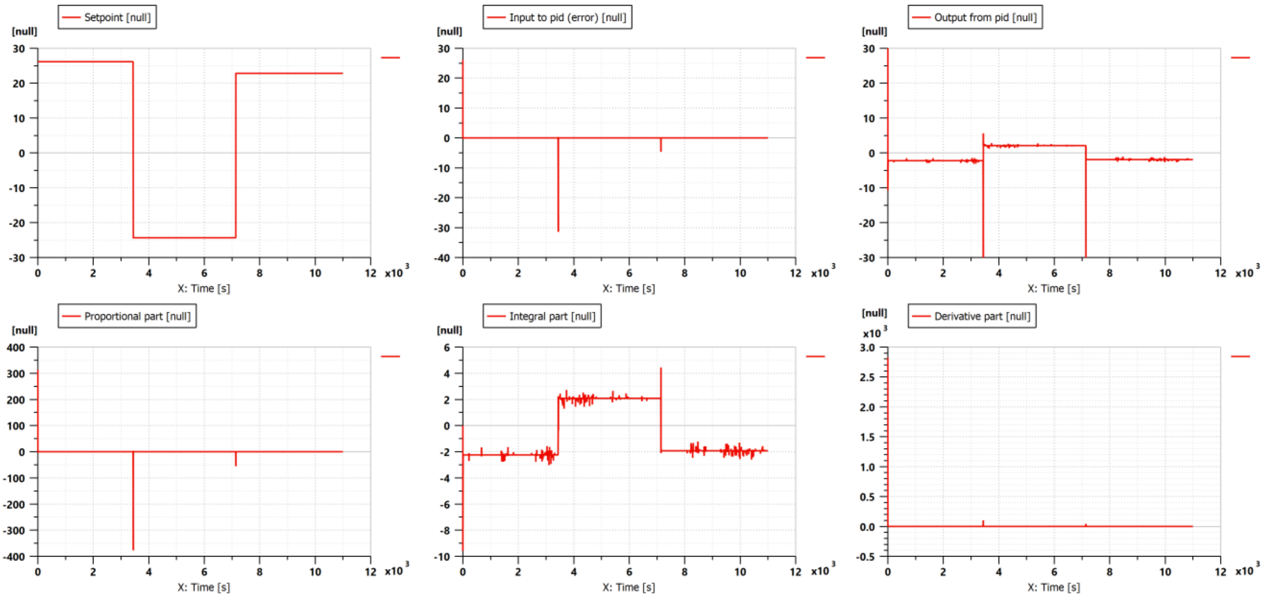


Fig. 9 - Evolution in time of the internal and external parameters of the PID controller

The group of graphs in Figure 10 shows: • the evolution in time of the setpoint parameter that represents the system control and the desired evolution in time of the process; • the process value which represents the variation in time of the system response to the setpoint parameter and • the error of the adjustment process. On the same graph one can also see the evolution over time of the adjustment error (in red), which has high values when changing the direction of travel or at start-up.

The graphs in figures 11 and 12 show in detail the variation over time of the same parameters presented in Figure 10. Figure 11 shows the stabilization time at start, which has a value of 0.3 s, and the value of the speed error - 26 mm/min. Figure 12 shows the stabilization time when changing the direction of travel; in this case, unlike the previously discussed case, the stabilization time is large, almost double – it has a value of 0.5 seconds; this delay is due to the fact that the proportional control valve must switch from the parallel position of the spool valve to the crossed position (or vice versa) passing through the centre position, the closed one. This problem can be prevented by using a 4/2 proportional directional control valve. In the same figure, one can notice that the error is 32 mm/min.

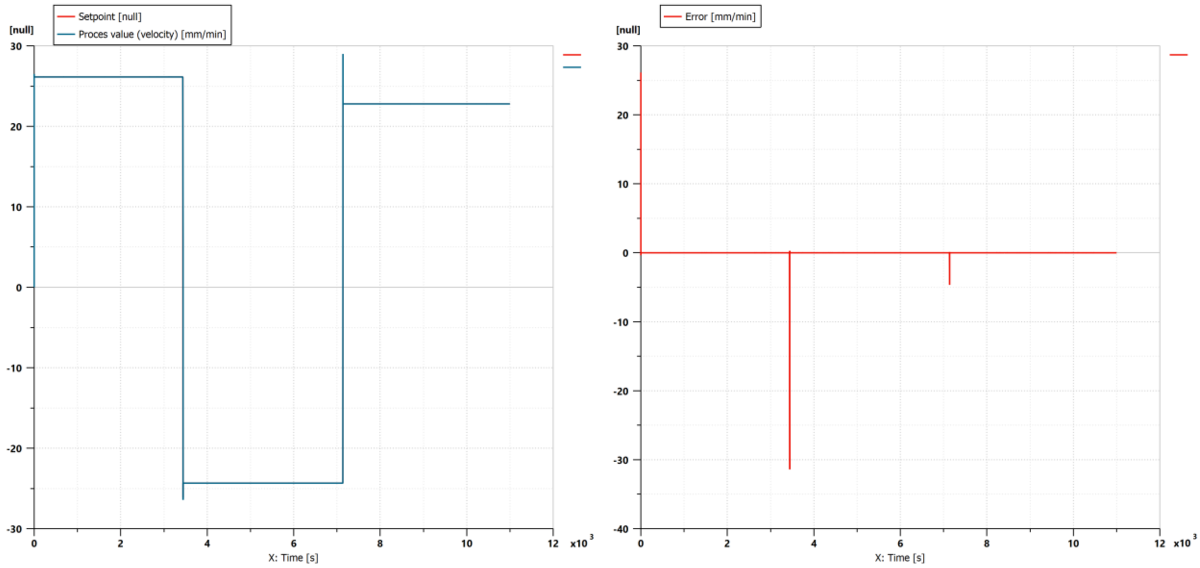


Fig. 10 - Evolution in time of the setpoint, process value and its error

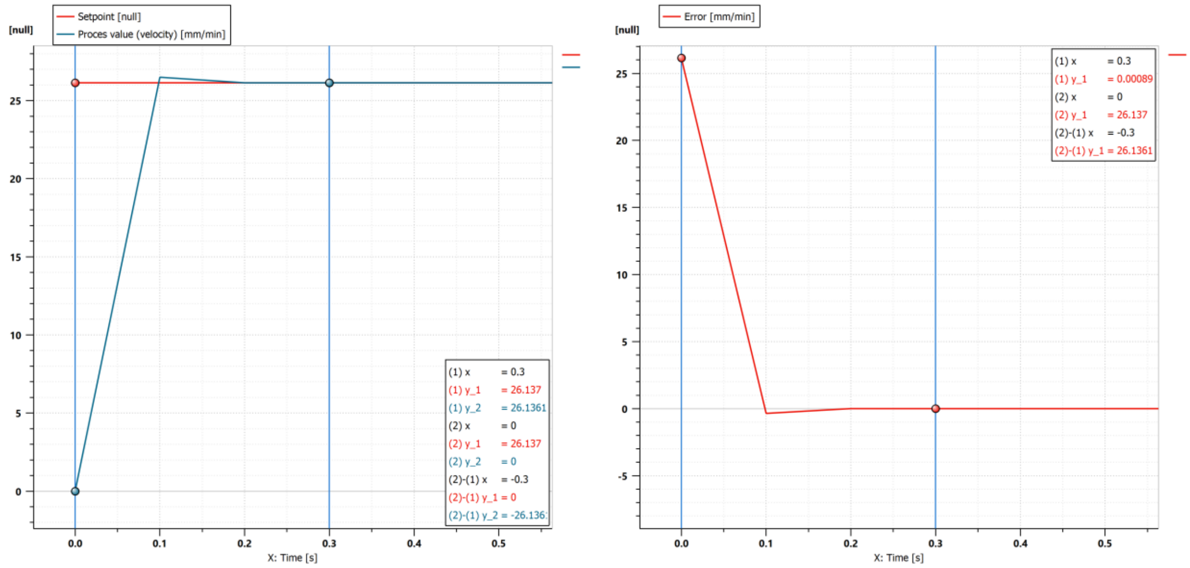


Fig. 11 - System stabilization time and error at start-up

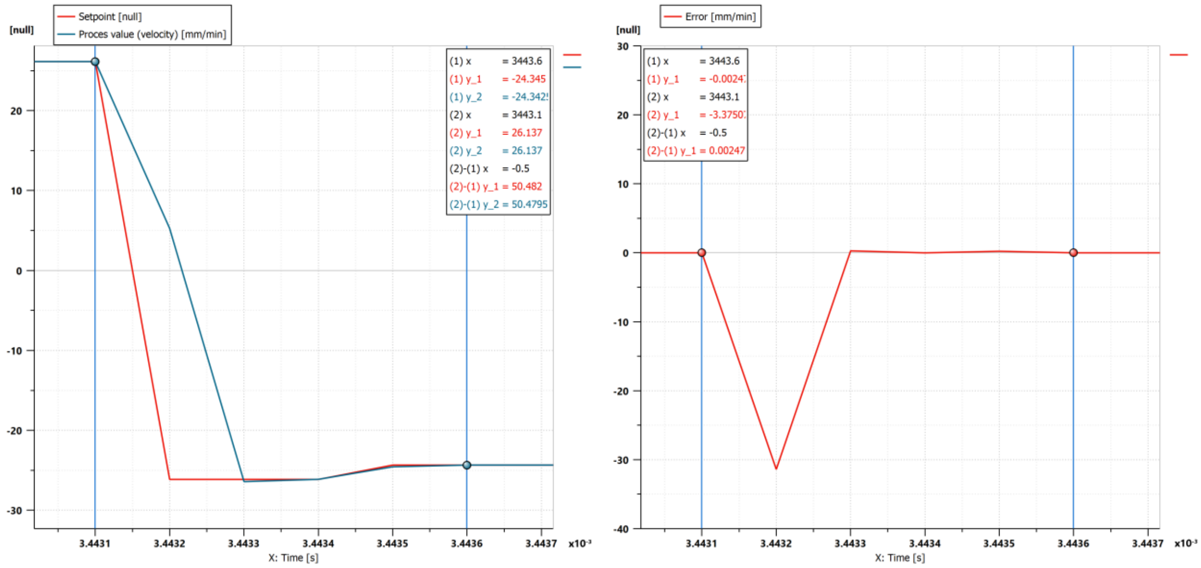


Fig. 12 - System stabilization time and error when changing the direction of travel

Figure 13 shows a detail of the error of adjusting the linear velocity of the spooling device with proportional control valve.

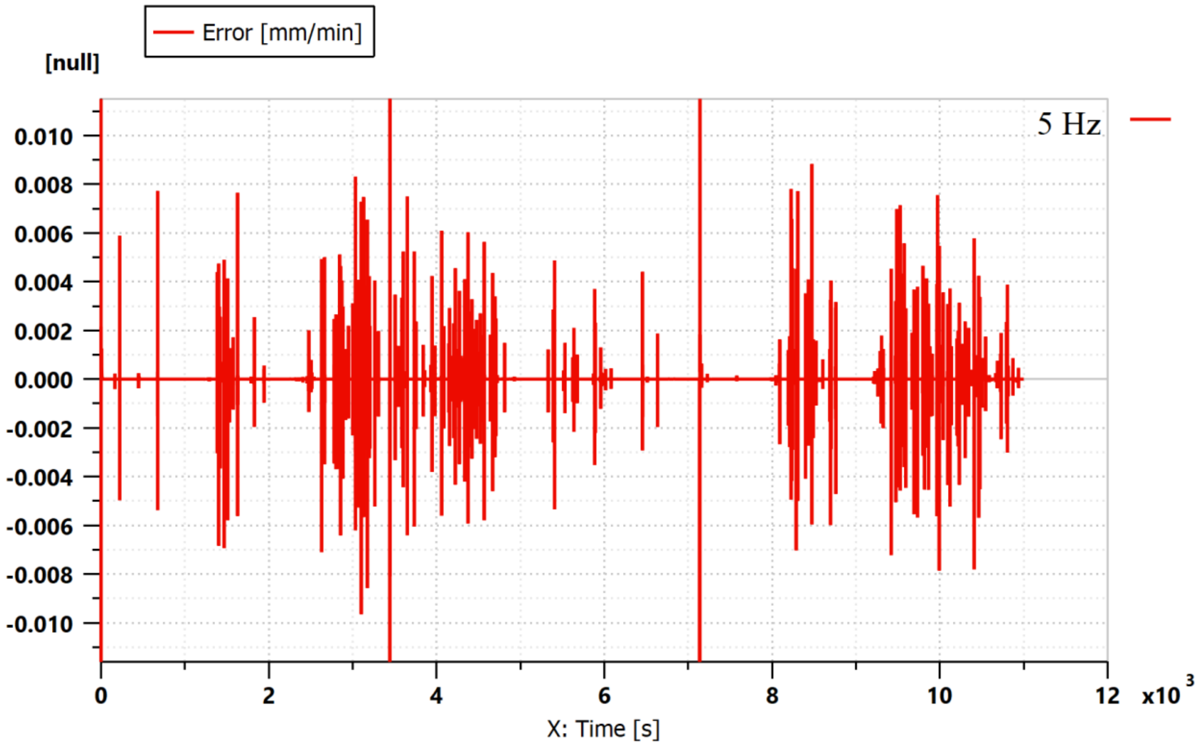


**Fig. 13 - Detail - the error of adjusting the linear velocity of the spooling device with proportional control valve**

Figure 14 shows a detail of the error of adjusting the linear velocity of the spooling device with servo valve.

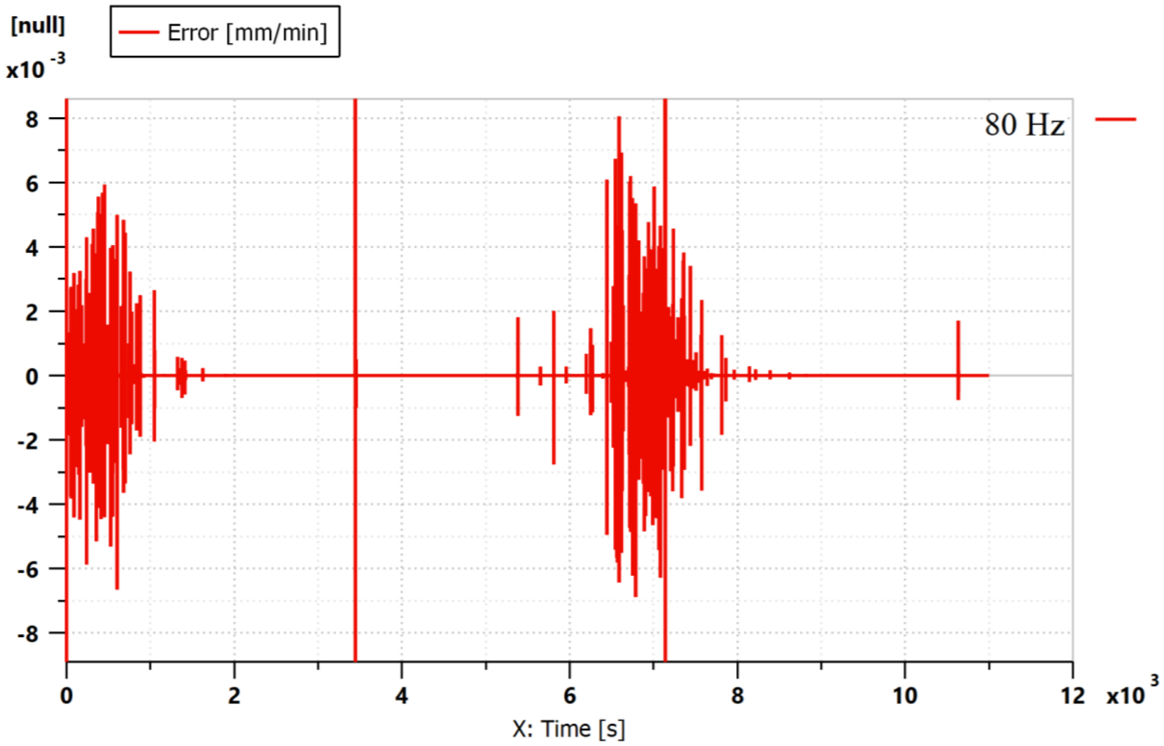


**Fig. 14 - Detail - the error of adjusting the linear velocity of the spooling device with servo valve**

Only the comparative graphs of the two speed control systems which showed significant differences were presented; among these, there are figures 6 and 7, as well as figures 13 and 14.

## CONCLUSIONS

Comparing the two speed control systems analysed in this article, the following conclusions can be drawn:

The control system with proportional directional valve is suitable for this system because the technological process is slow.

Both systems perform a sufficiently precise adjustment of the process, but the servo system is at least 4 times more expensive than a system consisting of a proportional directional valve and a PLC.

The servo valve control system has better accuracy and superior stability, which is suitable for faster technological processes, but it also has disadvantages, such as: high cost; it requires fine oil filtration; vibrations during the technological process can negatively influence the performance of process adjustment.

An important advantage of the control system with proportional control valve is that the pressure drops on it at maximum flow is only 10 bar, while at servo regulation the drop is 70 bar. Given that the pressure drop required to adjust the linear velocity is small and some of irrigation systems have as primary source of energy the pressure and flow from the irrigation pipe that drive a turbine which in turn drives the drum, the same turbine could also drive the hydraulic pump by means of a speed multiplier, and in this case a heat engine would no longer be necessary.

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